HuSIS: A Dedicated Space for Studying Human Interactions

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The Human-Surrogate Interaction Space (HuSIS) consists of a dedicated physical space, structures, and components designed specifically for carrying out controlled studies related to human-surrogate interactions. This article discusses the primary factors considered in the HuSIS design and the benefits of the common data-collection and analysis framework for HuSIS research.

The United States Marine Corps (USMC) trains and assesses Marines in a variety of skills. To train Marines to interact with humans (friendly and not-so-friendly), the USMC uses various stand-ins for real humans, or *human surrogates*. Currently, the types of surrogates include live human actors, virtual humans, and animatronic (robotic) humans. To support the USMC, the US Office of Naval Research (ONR) is pursuing a range of basic research related to human surrogates, such as how to realize the surrogates and assess the effectiveness of different surrogate characteristics in human-surrogate interactions. Evaluating and comparing human-surrogate interactions requires capturing and analyzing a spectrum of data, such as biometrics, body posture, gaze direction, facial expressions, and questionnaires.

To support the study of effective human-surrogate interaction techniques and modalities, ONR awarded us an equipment grant to support the development of a Human-Surrogate Interaction Space (HuSIS) at the University of Central Florida in the Institute for Simulation & Training. The HuSIS consists of a physical structure in a lab space and the supporting components that facilitate common virtual reality (VR) and augmented reality (AR) experiences, including immersive CAVE-style[1] and head-worn display experiences as well as robotic and mixed real and virtual physical interactions. The HuSIS also supports the collection of various human subject behavioral signals (such as head pose, body posture, and facial expression signals) and a variety of physiological signals.

At some level, the HuSIS is similar to other systems built to facilitate training and research with human surrogates in defense-related circumstances, such as the FlatWorld project at the University of Southern California's Institute for Creative Technologies (http://ict.usc.edu/prototypes/flatworld). However, rather than a space focused on fielding and testing various systems and methods, the HuSIS focuses more narrowly on human-surrogate interactions. Thus, when designing the HuSIS, we paid particular attention to how human-surrogate interaction studies in particular would be conducted, controlled, and monitored by one or more researchers. We also concentrated on how the data could be collected, within a compact space and with a common framework to avoid the repeated logistical overhead associated with the presentation and data-collection setup for each new study. (For more details, see the "A Common Framework for Human-Surrogate Interaction Experiments" sidebar.)

The HuSIS space usage and layout was inspired in part by the Virtual Human Interaction Lab (http://vhil.stanford.edu) developed by Jeremy Bailenson at Stanford University. Bailenson is a social psychologist who carries out large-scale human-subject research related to interactions with virtual humans. To facilitate his experiments, Bailenson architected his physical space with multiple rooms spanning a planned layout and design to support the "pipelining" of human subjects during experiments to increase subject throughput. That is, one subject can be answering a pre-questionnaire,

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while another is doing the experimental task and another is answering a post-questionnaire.

Our HuSIS design includes three related high-level goals. First, we wanted an instrumented space dedicated to human-subject experiments. Second, we wanted to support participant pipelining. Third, we wanted to control as many factors as possible that might unintentionally influence a participant's perceptions, mindset, or feelings. Previous research discusses many physical and technical considerations for collecting valid and useful data (for example, in usability testing for mobile devices[2]), and similar factors relating to balancing unobtrusiveness with data collection capabilities and quality also apply here.

Here, we describe the HuSIS design and realization, including the structural components, the array of input and output technology, and how everything works together. We discuss factors that we considered when making design decisions, look at the potential benefits to having a common data-collection and analysis framework, and explore some of our plans to expand and improve the system in the future, including the development of Transportable HuSIS (THuSIS) systems. Although we focus here on human-surrogate interactions, the HuSIS could be used for any VR/AR/robotic experiments that fit within the interaction space, and the design goals and decisions are largely generalizable to systems facilitating experiments with a range of applications.

A Common Framework for Human-Surrogate Interaction Experiments

The Human-Surrogate Interaction Space (HuSIS) provides a common framework for running user studies that includes the following:

- data collection for minimally invasive behavioral and biometric measures;
- tracking, sensors, and display;
- rendering (templates for known setup and display/sound capabilities);
- study procedures and live data-collection software; and
- data format, visualization, and analysis software.

Such a common framework affords efficiency in four areas:

- Experiment coding/development: common rendering framework for the known setup and display/sound capabilities.
- Experimental hardware setup: common tracking, sensors, and display setup.
- Running experiments: common procedures and data-collection software.
- Results analysis: common data format, visualization, and analysis software.

The common framework also affords portability of experiment design, data collection (for example, with our planned Transportable HuSIS units), and data analysis. This portability will allow for longitudinal metaexperiments, including cross-study comparisons and the reanalysis of previous studies with new insights and metrics.

HuSIS Layout and Design

The HuSIS design, appearance, and layout were driven by the requirements of three major user roles: participants taking part in human-surrogate interaction studies, researchers conducting and controlling the studies, and researchers developing and debugging the hardware and software used for the studies. In the case of study participants, we especially wanted to minimize unintentional influences on the participant's mindset and perceptions and on the context surrounding the interaction. This led to the following participant-inspired design goals:

- Participants should not see or hear other participants before, during, or after an interaction.
- Participants should not be distracted by stimuli unrelated to the experiment, such as equipment or people in other parts of the lab.
- Participants should not see any of the interaction setup prematurely.
- Participants should not see or hear researchers controlling the study behind the scenes.
- The part of the lab that the participant sees prior to entering the experiment space should appear as "normal" as possible.
- The participant's travel distance and time between questionnaires and interactions should be minimized.
- Participants should not feel restricted or encumbered by invasive tracking and data-capture sensors—that is, such devices should be visually subtle, minimize discomfort and motion restrictions, and not be heavy or bulky.

The following secondary goals aimed to help researchers easily develop and smoothly run studies:

- Researchers should have dedicated areas from which they can control and monitor the experiment.
- Control areas must provide visual awareness of everything going on both inside and around the experiment space.

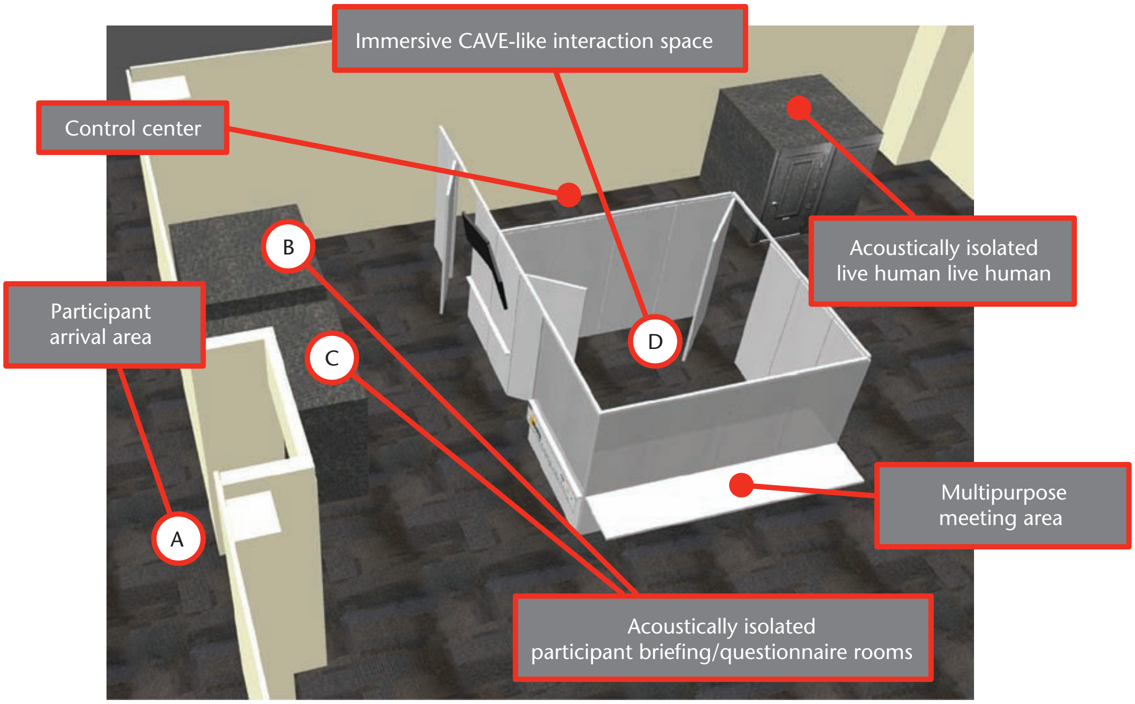

Figure 1. Layout of the Human-Surrogate Interaction Space (HuSIS) in a corner of our existing lab space. The HuSIS system consists of areas designed to facilitate participant pipelining throughput and minimize unintentional influences on the participant's mindset and perceptions and on the context surrounding the interaction. Multiple participants can be moved through areas A through D, while the researchers operate (out of sight) in the live interactor room and control center.

- Researchers should be able to reach participants quickly from control areas.
- When participants are not inside the experiment space, researchers should have easy access to it without being seen by participants.
- While developing or debugging experiments, researchers should have quick, easy access between control areas and the experiment space.
- Access to the experiment space should be wide enough to allow for bulky equipment to be moved into and out of the space, if needed.

The structure and layout of the lab in which the HuSIS was constructed (the preexisting walls, doors, ceiling air ducts, and so forth) also imposed some physical constraints on the HuSIS design. Broadly speaking, the final system consists of the following spaces: participant isolation rooms, a CAVE-like interaction room, a control center, a hallway connecting the previous three with the entrance to the lab, a room for a live interactor (for human-in-the-loop surrogate control), and a multipurpose meeting area outside the interaction room (see Figure 1).

Participant Rooms

We wanted participants to be comfortable during briefings and while working on pre/post questionnaires, without being distracted or influenced by other participants or interactions. To this end, we decided to use two commercially available sound isolation enclosures from a company called WhisperRoom (www.whisperroom.com). Designed primarily as semiportable recording or practice booths, these freestanding rooms come in various sizes and shapes. We chose a 7 × 7 foot room with a wide access door and a height extension option for an additional 10 inches of overhead space. This space comfortably fits a large desk, a chair, and two people. With this setup, both a researcher and a participant can be inside while the researcher explains questionnaire procedures or outfits the participant with any equipment prior to introducing him or her to the experiment space. Having two isolation rooms lets us fully isolate study participants from each other.

The existence of two noise-isolated rooms also allows us to pipeline the study participants, nearly doubling the experimental rate when including pre/post briefings and questionnaires. Figure 2 illustrates the pipeline process. A participant P_1 arrives for the study at area A. P_1 is then led into isolation room B for a pre-briefing and questionnaire (see Figure 3). As P_1 is finishing the pre-briefing and questionnaire, P_2 arrives for the study at area A and can immediately be placed into isolation room C. Then, P_1 is led into the interaction space D. While P_1 is doing the interaction, P_2

is completing the necessary pre-briefing and questionnaire. P_1 finishes the interaction and returns to isolation room B for a debriefing/post-questionnaire, while P_2 can immediately move to the interaction space D. As soon as P_1 has finished the debriefing/post-questionnaire, he or she can leave the lab, freeing up isolation room B for P_3, who has recently arrived and is waiting outside at area A. This process continues for subsequent participants, as Figure 2 shows, with participants alternating between the two isolation rooms.

Physical Structure

The walls of the HuSIS, which are free standing and installed on top of the existing lab carpeting, are from a company called DIRTT (www.dirtt.net), which has an extensive array of modular components that can be used together and customized to fit a particular configuration. Workscapes, a DIRTT partner company in Orlando, helped us design and generate the exact specifications for the structural walls, doors, and connected accessories (such as work surfaces and display mounts).

The walls themselves consist of a metal frame that can support modular wall tiles on both sides with denim insulation in between (mostly for sound, in our case). The tiles that make up the wall surfaces can be made from different materials and be different sizes from the other side of the same wall. For example, the interior of the interaction space has full floor-to-ceiling matte-white medium-density fibreboard tiles that provide large surfaces for front projection, whereas the tiles on the control center side of the wall are broken up vertically into two tiles with a horizontal work surface installed at the junction of the two. Some of the outward-facing walls have glass tiles (for use as whiteboards) or have shelves or trays that mount between tiles. The DIRTT walls also allow for cables to be fed under or along the base of the walls; this is particularly convenient for connecting equipment in the interaction room to computers in the control center.

Interaction Space

The central experiment space in the HuSIS is a roughly 13 × 13 foot square room, specially designed and outfitted with multiple input and output capabilities (see Figure 4). The room can be used for interactions involving real, virtual, or mixed-reality human surrogates as well as the context or environment around them.

Displays. Creating a compelling and immersive visual environmental context is an important

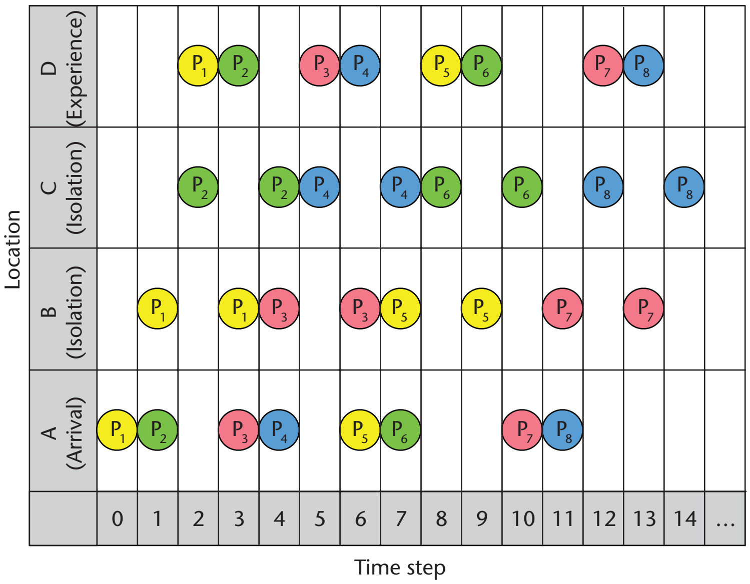

Figure 2. Participant pipelining for increased study throughput. Participants P_1 through P_8 can been moved through the interaction space without crossing paths. Areas A through D correspond to those labeled in Figure 1.

Figure 3. Acoustically isolated participant isolation rooms. These two rooms allow researchers to nearly double the experimental rate when including pre/post briefings and questionnaires.

aspect of the human-surrogate interactions that we study. Inside the interaction room, we achieve full 360-degree panoramic virtual environments that can contain one or more interactive virtual humans. All four walls are projected onto from edge to edge using ultra-short throw 1080p NEC U321H projectors mounted in the ceiling above the room. The 0.25:1 throw ratio of the projectors

Figure 4. HuSIS interaction space. This central experiment space is structured to support various input and output capabilities, including CAVE-like spatial augmented reality (SAR) and head-worn display experiences. Here we show a US Navy sailor visualizing the bridge of the USS Freedom, a littoral combat ship.

means a person can move to within a couple feet of a wall without occluding the projected imagery. (The exact proximity depends on the user's height.) Projector resolution is important because the imagery is spread across a large surface (13 feet wide); we use 1080p projectors, but higher-resolution projectors with a similar throw ratio would be preferable if cost was not a limitation. An Oculus Rift, or similar head-worn display, can also drop down from the ceiling for VR or AR interactions, in combination with projected imagery on the walls if desired. In "pure" VR situations with a head-worn display, in which the projectors are not needed for the interaction itself, projected imagery could still be used to set the context or environment of the interaction prior to the head-worn display being put on in the room.

One consideration for utilizing the full-wall projection was the two doors that provide access into the interaction room. We wanted doors that appeared as normal as possible from the outside, but still allowed for seamless interior projection across both the wall tiles and the doors. The doors were designed to open inward so that, when closed, they would be completely flush with the wall tiles. The door hinges stick out slightly, but they are a small enough protrusion that they have minimal noticeable effect on the projected imagery. The door handles, however, would have stuck out significantly farther, creating distracting shadows in the imagery being displayed on the wall. (The severity of the projector occlusion is increased due to the extremely short throw ratio and consequent sharp angle of the projection.) To fix this, we removed the interior door handles entirely, capping and painting over the two holes. We then moved the doorstops (normally fixed to the base of the wall) to the bottom of the doors. In this way they still function as doorstops (they hit the bottom of the wall, preventing the door from striking it) but also as foot handles for opening the doors from the inside.

Audio output. We considered sound to be a critical aspect of the experiences we plan to convey in the HuSIS. Because visible speakers would have interfered with projection, we instead used transducers to transform the walls themselves into speakers. Each wall has a transducer embedded inside a central wall tile, allowing audio to originate near the center of the wall imagery. The transducers are wired to an amplifier, which is then connected to one of the rendering computers. This setup lets us produce directional audio to accompany the immersive projected or HMD imagery.

Sensors. One of the defining unique capabilities of the HuSIS is the ability to collect large amounts of real-time data about a user, from full-body tracking to facial expression analysis and biometrics. Real-time tracking and sensors in CAVE-like systems are not new—traditionally, tracking or other real-time sensors have been used to drive the simulation itself (such as for head-tracked or dynamic viewpoint rendering). However, we are also particularly interested in using as much of this user behavioral and biometric data to develop new measures for analyzing user reactions during interactions with human surrogates. To this end, while sensor data can certainly be fed back into the live simulation, we also log everything during an interaction for more rigorous offline analysis.

Positional tracking and motion capture can be accomplished in several ways within our interaction room, depending on the specific requirements of the interaction. For six degrees of freedom (DOF) active or passive marker-based IR optical tracking, we use eight NaturalPoint OptiTrack cameras (http://naturalpoint.com). One or more Microsoft Kinect depth and color cameras can be used for coarse markerless positional or skeleton tracking. While we originally intended to also have a magnetic tracking system for applications that needed to avoid visible markers or IR illumination, in practice we found it unusable.

Collecting a variety of dense biometric data during human surrogate interactions is a key capability that requires a delicate tradeoff between data quality and precision and invasiveness for the participant. We use an Empatica E4 wristband (www.empatica.com) as a single, minimally invasive, wireless device capable of capturing biometric data about a participant before, during, and after an interaction. The E4 wristband is designed to be no more invasive or distracting than a snug wristwatch. In addition to having a three-axis accelerometer, the E4 can report blood volume pulse (BVP), heart rate variability (HRV), galvanic skin response (GSR), and skin temperature—all wirelessly in real time. We considered other physiological signals, including EEG, ECG, EMG, and respiration, but could not find sensor solutions that provided reliable and accurate data, were not overly invasive, and remained within our limited budget.

A crucial part of many interactions with human surrogates is verbal communication and conversation. Although it is relatively easy to record the speech of a computer-controlled or live interactor human surrogate, is it also essential that researchers have a clear record of anything the human user says. Again, we wanted to minimize the invasiveness while insuring constant, high-quality audio capture in a variety of situations with potentially noisy background sounds from the simulation itself. To achieve this, participants in the HuSIS can be outfitted with a wireless lavalier microphone (clipped to almost any clothing top) that transmits back to a mixer connected to one of the control computers. We use an Audio2000 AWM-6032UL mic system. An operator can listen live while also recording the audio using software such as Audacity.

Despite all the numerical data we are able to collect and analyze, there will always be times when researchers need to go back and review what actually happened—whether to confirm unusual conclusions or outliers from other data sources or to get a high-level understanding of which numerical measures might be interesting to look at. Therefore, multiple levels of video capture occur during a user study in the HuSIS. First, researchers in the control center need live video of any interaction taking place in the core room. However, they also may need to see other areas outside the room, such as the hallway along the preparation rooms or other lab spaces where people might be doing tasks that could interfere with a study.

To this end, we have a turnkey security camera system (Swann NVR8-7300), with several cameras providing different angles of the interaction space as well as other areas around the lab. Although this system is used primarily for live situational lab awareness of multiple participants during an experiment, the video can also be stored and retrieved for later review or analysis. Additionally, we placed multiple USB cameras around the interaction space for more detailed or study-specific video capture fed directly to the computers in the control center. This video can be logged or used for analysis in real time. Finally, high-definition (HD) camcorders provide the highest quality imagery and are also a backup source of recorded video unaffected by any computer issues, such as a disk failure or system crash.

Real-time facial expression analysis is already recognized as a potentially powerful tool in some areas, such as automatically and quickly measuring viewer reactions to TV commercials or detecting possible security threats via surveillance cameras. Researchers are also using it to study human-surrogate interactions.[3] Using one or more of the USB cameras that have a clear view of a participant's face, we explored different software to detect facial expressions in real time (iMotions' Emotient, Affectiva, and Faceshift). We are using Emotient to detect basic emotions such as joy, anger, surprise, fear, contempt, sadness, and disgust. The software can also be upgraded to explore in-depth details of 19 action units according to the Facial Action Coding System (FACS). Each action unit represents a unique muscle group that can be objectively recorded and analyzed.

Figure 5. HuSIS control center. The large wall-mounted display can show one or more views from the live situational awareness security camera system, while the four smaller wall-mounted displays mirror the imagery being projected on the four interior walls in the HuSIS central experiment space.

Interactor Room

A third WhisperRoom sound-isolation booth provides a place for an *interactor*, a live human to control one or more surrogates during an experiment. The close proximity to the interaction space gives us the option for direct cables for audio or video when extremely high quality is necessary. The noise isolation allows the interactor to speak loudly or shout while ensuring that the participant hears only the sound from the desired speakers, spatially aligned with the surrogate. This isolation booth can include various tracking and interaction devices, as well as displays for visual feedback for the interactor.

Control Center

The control center is adjacent to the interaction room, with easy access to both the hallway next to the preparation booths and the interaction room (see Figure 5). The rendering, audio, tracking, logging, and analysis control is distributed across three workstations. A large wall-mounted display can show one or more views from the live situational awareness security camera system, while four smaller wall-mounted displays mirror the imagery being projected on the four interior walls.

The control center computers have Intel XEON processors capable of handling heavy workloads with multiple rendering, tracking, logging, or other processes running simultaneously. Each computer also includes two 6-Gbyte Nvidia GeForce GTX 980Ti graphics cards so they can comfortably drive six or more displays (two desktop displays and four wall projectors) or a head-worn display (such as an Oculus Rift). The computers have a solid-state disk boot drive and a much larger pair of platter disk drives operating in a hardware controlled RAID 0 configuration for logging large amounts of data in real time.

Multipurpose Whiteboard Wall and Work Surface

The outside wall of the interaction room opposite the control center has writable glass whiteboard tiles spanning the wall, along with chairs and a work surface (see Figure 6). The work surface consists of five adjacent table segments—IKEA Norberg wall-mounted drop-leaf tables—each of which can be collapsed and folded down. This allows some of the surfaces to be used as a desk or table, while others are folded down to give easy access to the writable whiteboard surface.

This multipurpose space can be used for larger group discussions and debriefings or as a place lab visitors can sit and work. The whiteboard surface extends around the corner into the hallway between the isolation rooms, the interaction space, and the control center. This hallway space also contains two wall-mounted TVs that can be used to provide information to study participants or, in the case of live demonstrations, to show simultaneous live video of people inside the interaction room along with imagery of what they are currently seeing.

Managing the User Experience

One important aspect of the experiment space that we considered was carefully managing what study participants were exposed to before beginning a particular experiment. Seeing or hearing other participants, unrelated equipment, or even the experimental setup itself can cause immediate changes in a person's thinking, expectations, and subsequent behavior and questionnaire answers. We were careful to arrange the HuSIS space such that study participants walking into the lab see only a relatively normal-looking wall with a couple of closed doors—not unlike a wall in a hallway they would be used to seeing. The doors themselves, both in the interaction space and the control center, are standard widths and heights, with regular handles on the hallway side to prevent, as much as possible, participants from feeling like they are entering an abnormal or experimental space.

We considered having a raised floor for the interaction room. This would have allowed us to put a low-frequency subwoofer (such as Guitammer's ButtKicker) under the floor to control tactile sensations felt through a participant's feet (for example, feeling the ground shake as a heavy virtual vehicle drives by). This would also have let us run cables under the floor, if desired.

A raised floor, however, would have increased the perceived abnormality of the interaction space, unless the entire entry, hallway, isolation rooms, and interaction space were all raised as well. We also considered that a raised floor would it make it more difficult to move large equipment into or out of the interaction space.

Data Collection and Analysis

Historically, much of the data used to determine important factors like presence, copresence, or empathy in studies with human-surrogate interactions has come from participant responses to questionnaires. Although we provide support for such questionnaires within the HuSIS, we are interested in augmenting questionnaires with dense real-time sensor data to better measure human reactions and perceptions. Many of our data-collection and analysis design goals are not unique to human-interaction studies or even studies within an immersive space. Previous work has explored and enumerated beneficial capabilities of data collection in similar experimental settings,[4] including but not limited to having a single point of data control, data synchronization, and the ability to quickly filter large amounts of raw data into useful results.

The same software framework we purchased to use for facial expression analysis (iMotions) can be expanded to import additional arbitrary data sources to be logged simultaneously. We used iMotions to log all sensor data in some of our earlier experiments, but we want more flexibility in how the data is logged and have been exploring alternatives. We have considered both writing our own robust data-collection and analysis framework and using an existing tool called Ubitrack (http://campar.in.tum.de/UbiTrack/WebHome). Although designed primarily for tracking, Ubitrack can function as a way to decouple an application from general sensor data and provide a means to synchronize and log that data. Metrics based on the analysis of common data collected across many experiments offers significant benefits:

Figure 6. Multipurpose work space. The outside wall of the interaction room consists of a whiteboard wall and wall-mounted drop-leaf tables that enable group discussions, debriefings, or other uses.

- *Temporal granularity before, during, and after an interaction*. Questionnaires might provide a glimpse of how a participant remembered feeling during an interaction (typically reported after the entire interaction has taken place), but what about changes to a participant's perceptions throughout the interaction? Live sensor-based metrics could let us pinpoint precisely when a participant begins building a deeper connection with a virtual human and may provide a clue as to what component of the interaction led to the connection. Real-time analysis could even be fed back into a simulation to adapt the surrogate's behavior or surrounding environment, in the middle of an interaction, based on how a human participant is responding.
- *Cross-study comparison*. Measured results from multiple user studies all conducted in the common HuSIS framework can be more objectively compared. Even when we do not necessarily know what a particular behavior or biometric signature implies about a user's state of mind, we can still note differences between studies that could lead to insights for new hypotheses.
- *Retrospective data analysis*. As new metrics are discovered, we can reanalyze data collected in

previous studies to look for additional evidence or find new results that were not originally apparent.

Having a common data-collection and analysis framework helps eliminate overhead for developing and setting up logging every time a new study is designed. It also achieves consistency and simplicity in how all the data is logged (same program, same logged format) for the researcher running a study. Ideally, the data collection would be akin to a one-button solution rather than requiring a researcher to start and stop many different logging processes manually. Although such a one-button solution would avoid user mistakes (such as forgetting to start the logging process), we are also interested in robust data-logging feedback and control. This includes being able to easily and more intuitively select which sensors should be used and logged and receiving live feedback about the state of the sensors—data is being received, looks valid, and so forth.

Lessons Learned

Over the course of the construction and subsequent use of the HuSIS, some unanticipated issues and considerations arose. The issues ranged from minor inconveniences to equipment being unusable in the way we had hoped.

First, we originally bought a Polhemus G4 wireless magnetic-tracking system for occlusion robustness and to avoid IR illumination and visible markers. The magnetic source was suspended above the user's head in the middle of the room. We expected some distortion as the sensors approached the walls, but we anticipated only moderate distortion that could be mapped once and then factored out of later measurements. In practice, the distortion was far greater and widespread, and we now primarily rely on optical tracking solutions.

Although the WhisperRoom enclosures are used widely around the world, they are not fire-rated products as shipped. Thus, following a review with the University of Central Florida's Facility Safety Group, we are in the process of treating the interior booth materials to make them flame retardant and are installing sprinkler heads inside the enclosures. If you want to use similar enclosures, it is probably worth looking into fire-safety concerns early in the design process.

Also, although the DIRTT walls are sturdy, they will move slightly, for example, as doors are opened or closed. Consequently, we decided that sensitive or calibrated equipment should not be mounted to the walls. Projectors and other sensitive equipment are mounted to the ceiling grid and scaffolding.

Another usage constraint is that some equipment may be tethered by strict length limitations on connecting cables. For example, a particular video-see-through AR system was unreliable when used with a longer USB extension cable. Even though we designed the space so that computers in the control center would be adjacent to the interaction room, such length limitations can still greatly restrict the user range.

For AR and other applications where study participants need to see both real and virtual objects, the quality of interior lighting is important. Without controlled interior lighting, people and objects inside the room are lit by the larger lab lights or light reflecting from our front-projection surfaces, which can vary significantly with the displayed content during an interaction. For that reason, we are in the process of installing interior lighting that will give us control over spatial and color characteristics, while avoiding illumination of the projection surfaces.

Lastly, we ran into complications regarding concurrent access to the control center and the interaction room. Although a majority of the application development occurs from the computer terminals in the control center, there are some cases where real-time visual feedback from inside the interaction room is advantageous. Examples of this include tracker calibration or adjusting spatially situated events. In cases like these, we use a wireless keyboard and mouse for input and duplicate the primary computer display output to one of the secondary High-Definition Multimedia Interface (HDMI) inputs on one wall projector.

Up Next: Transportable HuSIS Units

The HuSIS provides excellent space and infrastructure for human-surrogate interaction studies in a lab setting, but it cannot be used to capture more ecologically valid VR data outside the lab.[5] Aside from participants knowing that they are entering research lab space, some interactions only naturally occur in specific locations. Likewise, certain populations may not be readily available to come to a lab. We have recently been awarded a complementary ONR equipment grant to build multiple Transportable Human-Surrogate Interaction System (THuSIS) units. These will be almost entirely self-contained, slimmed down, but still powerful, mobile versions of the HuSIS (see Figure 7).

Each THuSIS unit will consist of a heavy-duty flight case with lockable wheels. The front of the case will open to reveal shelves, the top of which

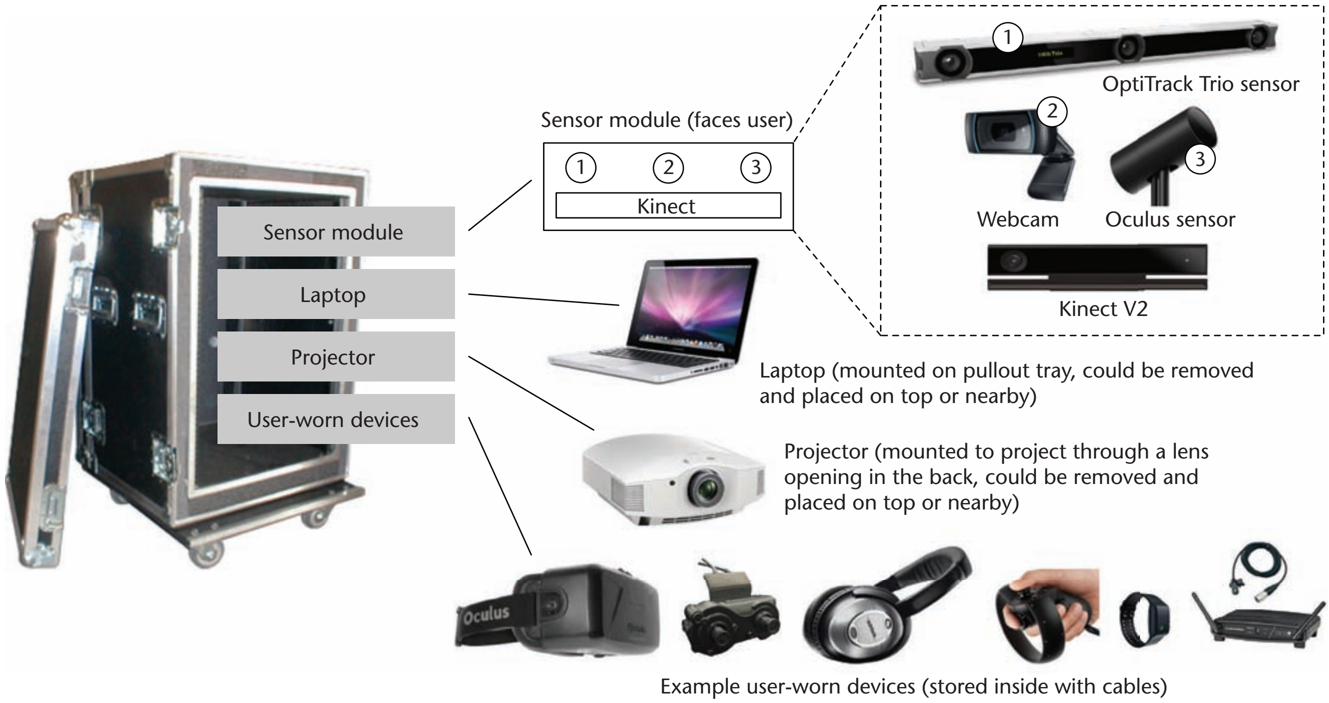

Figure 7. A Transportable Human Surrogate Interaction System (THuSIS) unit. An Office of Naval Research (ONR) Defense University Research Instrumentation Program (DURIP) grant is supporting the development of six such units, which could be used together in one location or independently in separate locations to increase their effectiveness and impact.

will contain a tracking and sensor bar consisting of an OptiTrack Trio, an HD Webcam, an Oculus (or similar head-worn display) sensor, and a Microsoft Kinect. A drawer below the tracking and sensor bar will pull out to reveal a work tray with a laptop that will be used to drive the simulation and log data. A projector will be on the next shelf. It will project out through a hole in the back of the flight case onto any wall or surface that happens to be available; or it can be removed from the case and set on the floor or another object—all depending on the specific available setup. A bin at the bottom of the case will contain a head-worn display and various input and output devices (such as an Oculus Touch), a head-worn display-mounted camera system for video-see-through AR, noise cancelling headphones, an E4 wristband for measuring biometric data, and a lavaliere mic for audio capture. Stereo speakers embedded in the case will provide audio output when headphones are not used or when multiple people are using the system simultaneously. The case will have an external standard power cord and the ability to connect to a wired or wireless network as needed for remote interaction and to upload collected data to a common server.

These THuSIS units will have multiple operating modalities, depending on the specific situational needs:

- Individual units could be used remotely to collect data in widely different locales, allowing for a much broader set of study demographics.
- Multiple units could be used remotely in synchrony to bring people from distant locations into a common interaction where each user is represented by an avatar that moves based on the tracked user, but may have any virtual appearance.
- Multiple units could be chained together in the same location with one or more users for greatly increased projected field of view or tracked area. With the known and calibrated relative spatial positioning of each unit, the embedded speakers could be used for synchronized directional audio.
- One or more units could be used simultaneously in the lab to greatly increase the throughput of participants in a study that does not require the full HuSIS.
- Units could be easily taken to other locations (such as museums and classrooms) for outreach, in an effort to expose a wide audience to human-surrogate studies and general AR/VR applications.

THuSIS units will run a variation of the same data-logging framework used in the HuSIS. Thus, the same analysis and comparison metrics could be used for remotely collected data—in particular from THuSIS units deployed for in situ data collection. Our envisioned uses are twofold. First, using multiple units together (for example, in our current lab at UCF) will allow us to gather data from subjects or provide training demonstrations in parallel—at the same time in nearby but isolated locations. This will let us collect more experimental data in the same amount of time or collect the same amount of data in a shorter time. Second, we envision using the units independently in separate locations to either broaden the demographics of our subjects—for example, by carrying out experiments in a shopping mall—or narrow our focus to specific scenarios at a specific site, such as a Navy or USMC base. We also envision using the units in some combination of these scenarios.

Our initial vision for the HuSIS was a research space that provides many possible input and output modalities and facilitates a range of human-surrogate user studies. In the process of designing and constructing the HuSIS, we also discovered a need for transportability. Investing in the additional effort needed to make a system transportable will allow us to reap the benefits of in situ experiments for more ecologically valid results and conduct on-site demonstrations for community outreach. We hope that our THuSIS system ideas will inspire others who are considering a complete VR system.

To date, the HuSIS and THuSIS designs have primarily focused on human-surrogate interaction. We see potential for the HuSIS to be used in other VR experiments, and perhaps any human-subject experiments where researchers want to quantify human behavior and physiology. Our hope is that others will leverage our design goals and decisions to build similar systems that enable new research.

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